

## Ground Operations of the ISS GNC Babb-Mueller Atmospheric Density Model

The ISS GNC system was updated recently with a new software release that provides onboard state determination capability. Prior to this release, only the Russian segment maintained and propagated the onboard state, which was periodically updated through Russian ground tracking. The new software gives the US segment the capability for maintaining the onboard state, and includes new GPS and state vector propagation capabilities.

Part of this software package is an atmospheric density model based on the Babb-Mueller algorithm. Babb-Mueller efficiently mimics a full analytical density model, such as the Jacchia model. While Jacchia is very robust and is used in the Mission Control Center, it is too computationally intensive for use onboard. Thus, Babb-Mueller was chosen as an alternative. The onboard model depends on a set of calibration coefficients that produce a curve fit to the Jacchia model. The ISS GNC system only maintains one set of coefficients onboard, so a new set must be uplinked by controllers when the atmospheric conditions change.

The onboard density model provides a real-time density value, which is used to calculate the drag experienced by the ISS. This drag value is then incorporated into the onboard propagation of the state vector. The propagation of the state vector, and therefore operation of the Babb-Mueller algorithm, will be most critical when GPS updates and secondary state vector sources fail. When GPS is active, the onboard state vector will be updated every ten seconds, so the propagation error is irrelevant. When GPS is inactive, the state vector must be updated at least every 24 hours, based on current protocol. Therefore, the Babb-Mueller coefficients must be accurate enough to fulfill the state vector accuracy requirements for at least one day.

A ground operations concept was needed in order to manage both the onboard Babb-Mueller density model and the onboard state quality. The Babb-Mueller coefficients can be determined operationally in two ways. The first method is to calibrate the coefficients in real-time, where a set of custom coefficients is generated for the real-time atmospheric conditions. The second approach is to generate pre-canned sets of coefficients that encompass the expected atmospheric conditions over the lifetime of the vehicle. These predetermined sets are known as occurrences. Even though a particular occurrence will not match the true atmospheric conditions, the error will be constrained by limiting the breadth of each occurrence.

Both methods were investigated and the advantages and disadvantages of each were considered. The choice between these implementations was a trade-off between the additional accuracy of the real-time calibration and the simpler development for the approach using occurrences. The operations concept for the frequency of updates was also explored, and depends on the deviation in solar flux that still achieves the necessary accuracy of the coefficients. This was determined based on historical solar flux trends. This analysis resulted in an accurate and reliable implementation of the Babb-Mueller coefficients and how flight controllers use them during real-time operations.